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The content and potential ecological risk assessment of heavy metals in coastal wetlands around the Bohai Sea

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Abstract: Coastal wetlands play a vital role in the migration and transformation of heavy metal pollutants in watersheds. There were 30 surface sediment samples that were analysed to investigate the distribution and ecological risks of heavy metals in the coastal wetlands around the Bohai Sea. Our results showed that the average concentrations of Pb, Cr, Ni, Cu, Zn, and Cd in these wetlands were 17.92 ± 5.81, 50.29 ± 20.50, 31.53 ± 9.71, 25.37 ± 4.29, 80.13 ± 15.11, and 0.92 ± 0.54 mg/kg, respectively. Relative to other wetlands, Pb (25.43 ± 2.68 mg/kg) and Cd (1.67 ± 0.06 mg/kg) contents were higher in the Liaohe Delta wetland (LHDW). Cu (28.44 ± 3.71 mg/kg), Cr (83.11 ± 5.80 mg/kg), and Ni (45.91 ± 3.02 mg/kg) contents were higher in the Yellow River Delta wetland (YRDW). The Zn (120.86 ± 7.41 mg/kg) content was higher in the Qilihai wetland. Heavy metal concentrations in coastal wetland sediments are shown to be positively correlated with organic matter content. Our results showed that the concentration of heavy metals decreases with increasing sediment particle size. In this study, Cd showed the highest pollution index and, therefore, more attention should be paid to the potential ecological risks of Cd in coastal wetlands around the Bohai Sea, especially in the LHDW and YRDW.

Keywords: Bohai rim; Reed coastal wetland; toxic element; pollution assessment; source analysis

Research on heavy metals has been prioritised due to their high toxicity, high bioaccumulation potential, and environmental persistence (Liu et al. 2016). The primary sources of heavy metals in soils include agricultural fertiliser, pesticides, atmospheric deposition, sewage irrigation, mining activities, and vehicular emissions (Zhao et al. 2020). Heavy metal pollution can disrupt soil structure and threaten the growth of flora and fauna. Heavy metals accumulated in living organisms can eventually enter the human body through food consumption and cause chronic poisoning, threatening human safety (Liu et al. 2016).

Coastal wetlands play an important role in filtering, settling, and transforming environmental pollutants within the watersheds that connect land and sea (Gao et al. 2014). The coastal wetland ecosystem has been seriously damaged by the intensification of industrial pollution and human activities, and heavy metal pollution has become an important factor in its degradation (Yang et al. 2010, Ouyang et al. 2018). For example, Wang et al. (2011) reported a significant increase in heavy metal content (particularly Cd) over the last century in the sediments of the Qi'ao wetland in the Pearl River Estuary of China. Liu et al. (2012) described the pollution levels of heavy metals in the coastal wetland of the Yellow River Delta (YRD) and ranked them in order of significance (Cd > Hg > Cu > Cr > Pb > Zn). Huang et al. (2019) showed that Cu, As, Cd, and Hg have caused moderate environmental pollution in the Liaohe Delta (LHD) wetlands. Zhang et al. (2020) found different pollution from Cr, Hg, and Cd in the rivers flowing into the sea near Jiangsu Province. Similar studies have also suggested that the sediment in the wetlands of the Yangtze Estuary was

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seriously polluted by Cd (Bai et al. 2011, Zhang et al. 2021). Moreover, accumulated heavy metals in coastal wetlands can be released into the overlaying water under certain conditions, causing offshore pollution (Wang et al. 2010, Huang et al. 2019). Consequently, it is important to investigate heavy metals' content and potential ecological risks in coastal wetlands.

Large amounts of land-based pollutants flow into the Bohai Sea and significantly deteriorate the water quality because of its semi-enclosed geography and weak water exchange with outside seawater (Gao and Chen 2012). Although many studies have investigated heavy metal pollution in soil, rivers, and the coastal sea around Bohai, little is known about the heavy metal distribution within the coastal wetlands surrounding Bohai (Bai et al. 2011, Huang et al. 2019, Zhang et al. 2021). In this study, we hypothesised that (1) the coastal wetlands around Bohai were seriously polluted by heavy metals due to regional urbanisation and economic development in past decades, and (2) the heavy metal pollution differed significantly among different wetlands. To investigate the heavy metal pollution of coastal wetlands, we collected the sediments in the 10 major reed wetlands around the Bohai Sea, and we studied the distribution characteristics and potential ecological risks of the heavy metals. Our results provide a scientific basis for protecting and managing coastal wetlands.

MATERIAL AND METHODS

Study area and sample collection

Many large rivers, including the Yellow River, Hai River, Luan River, and Liao River, converge around the Bohai Rim. Extensive coastal wetlands (37°43'–40°58'N, 117°17'–21°42'E) have developed in the estuaries of these rivers and are located across Shandong, Hebei, and Liaoning provinces in northern China. In this study, 10 major reed wetlands surrounding the Bohai Sea (Figure 1) were selected: Yellow River Delta wetlands (YRDW), including Experimental Zone

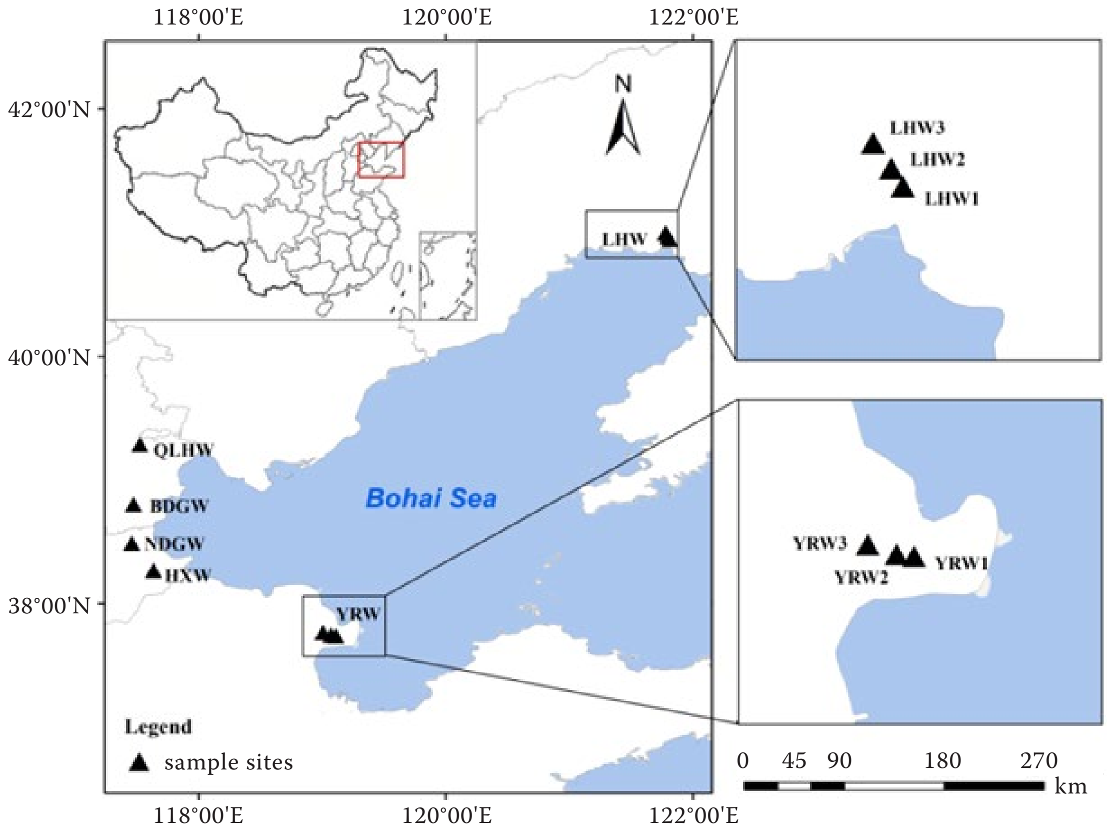

Figure 1. Distribution of sampling sites (Yellow River Delta wetlands (YRDW), including Experimental zone wetland (YRW1), Buffer zone wetland (YRW2) and Key zone wetland (YRW3); Bohai Bay coastal wetlands (BHBW), including Haixing Wetland (HXW), Nandagang Wetland (NDGW), Beidagang Wetland (BDGW) and Qilihai Wetland (QLHW); Liaohe Delta wetlands (LHDW), including Experimental Zone wetland (LHW1), Buffer Zone wetland (LHW2) and Key Zone wetland (LHW3))

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wetland (YRW1); Buffer Zone wetland (YRW2) and Key Zone wetland (YRW3); Bohai Bay coastal wetlands (BHBW), including Haixing Wetland (HXW); Nandagang Wetland (NDGW), Beidagang Wetland (BDGW) and Qilihai Wetland (QLHW); Liaohe Delta wetlands (LHDW), including Experimental Zone wetland (LHW1), Buffer Zone wetland (LHW2), and Key Zone wetland (LHW3). Except for YRW1 and LHW1, all of the wetlands were restored wetlands. Freshwater was drained through sluices into the restored wetlands to decrease sediment salinity, increase plant biomass, and increase soil organic carbon (SOC) content (Bai et al. 2011).

These wetlands were formed on the bare land that was created from large amounts of upland sediment transported down by rivers. These wetlands are mainly covered by reeds (*Phragmites australis* (Cav.) Steud.) with a vegetation cover of > 90%. The sediment samples were collected during the dry season (December 2018) with a water depth of 0–50 cm above the surface sediment. We collected samples from three representative sites at the centre of each wetland to minimise edge effects and physical disturbance. Five surface sediment samples (0–10 cm) were randomly collected at each sample site to form a representative sample using a sediment gravity core sampler (JC-801B, Huaye, China). In total, 30 surface sediment samples were collected from the coastal wetlands around Bohai. In the lab, the samples were freeze-dried, impurities were removed before being crushed through a 100 mesh sieve and stored in a refrigerator at 4 °C for further analysis.

Sample analysis

Sediment physiochemical properties analysis. The water content of each sediment sample was determined by drying the sediment at 105 °C to constant weight. The pH was measured using a pH meter with a soil-to-water ratio 1:2.5. Water-soluble salinity was determined using a salinometer. Total organic carbon (TOC) was analysed using an elemental analyser (Elementar, Vario MACRO Cube, Tokyo, Japan), and particle size was determined using a laser diffractometer (Mastersizer 2000, Malvern, UK).

Determination of heavy metals in sediments. The sediment samples were thoroughly digested with a mixture of acids containing HCl-HNO_3-HF-$HClO_4$. Next, the contents of Pb, Cr, Ni, Cu, Zn, and Cd in the digestion were determined by an inductively coupled plasma-mass spectrometer (ICP-MS, PerkinElmer Elan DRC II, Hong Kong, China). For quality control, a standard sediment sample GBW07333 was analysed in the experiment with a standard deviation of less than 5% for all heavy metals.

Risk assessment of heavy metals in sediments

Geo-accumulation index. The geo-accumulation index, I_{geo}, is an effective metal pollution assessment index for sediments.

$$I_{geo} = \log_2(C_n / 1.5B_n) \quad (1)$$

where: C_n – measured heavy metal (n) concentration in the sediments; B_n – background value for typical heavy metal (n), and 1.5 is the background correction factor due to lithogenic influences (Wang et al. 2016). The I_{geo} value is classified into seven grades (Chai et al. 2006).

Potential ecological risk index. The potential ecological risk index method is widely used to assess the ecological risks of heavy metals in sediments. According to this method, the potential ecological risk coefficient (E^i_r) of a single element or the potential ecological risk index (R_i) of multiple elements can be calculated using the following equations:

$$C^i_f = C^i_o / C^i_n \quad (2)$$

$$E^i_r = T^i_r \times C^i_f \quad (3)$$

$$\mathrm{R}i = \sum_i^n E^i_r = \sum_i^n T^i_r \times C^i_f \quad (4)$$

where: C^i_o and C^i_n – heavy metal contents in samples and the geochemical background values, respectively; C^i_f – monomial contamination factor; T^i_r – toxic response factor of element *i* and the toxic response factor for Pb, Cr, Ni, Cu, Zn, and Cd are 5, 2, 5, 5, 1, and 30, respectively (Shen et al. 2020). The relationship between the assessment index, the pollution level, and potential ecological risk was shown by Guo et al. (2010).

Nemerow pollution index. The Nemerow pollution index (P_N) assesses the degree of overall heavy metal pollution and includes all analysed heavy metals. P_N is calculated based on the following formula:

$$P_N = \sqrt{P^2_{i\max} + P^2_{iave}} / 4 \quad (5)$$

where: P_N – Nemerow pollution index; $P_{i_{max}}$ – maximum value of single pollution index, and P_{iave} – mean contamination factor of a metal. Based on P_N, five classes of pollution levels were created by Wu et al. (2012).

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Statistical analysis

The data were reported as the mean and standard deviation of three replicates. A two-tailed Pearson correlation analysis was used to determine the correlations between the heavy metal contents and the physicochemical parameters of the sediments. Pearson correlation analyses were conducted using the SPSS software package (Washington, USA).

RESULTS

Physiochemical properties of sediments

The relatively lower water content of sediments ranged from 22.47% to 39.9% because the samples were collected in the dry season (Table 1). The sediment pH was slightly alkaline, with values ranging from 7.66 to 8.6. The BHBW demonstrated relatively higher pH values (mean, 8.36) while the YRDW and the LHDW displayed relatively lower pH values (mean, 7.77 and 7.88, respectively). The restored wetlands were less affected by sea water, resulting in lower water-soluble salt content (WSSC) ranging from 1.52 to 13.44 g/kg, and the LHDW exhibited higher WSSC ranging from 7.40 to 13.44 g/kg. The TOC content ranged from 0.21% to 5.7%, with an average of 1.61%. The highest TOC content was reported in the QLHW (5.7 ± 0.17%), while the lowest TOC content was measured in the LHW3 (0.21 ± 0.13%). The sand and silt content ranged from 53.02% to 81.37% and 15.84% to 39.73%, respectively.

Contents and distribution characteristics of heavy metals in sediments

The average concentrations of six heavy metals were as follows: Pb, 17.92 ± 5.81 mg/kg; Cr, 50.29 ± 20.50 mg/kg; Ni, 31.53 ± 9.71 mg/kg; Cu, 25.37 ± 4.29 mg/kg; Zn, 80.13 ± 15.11 mg/kg; and Cd, 0.92 ± 0.54 mg/kg. Notably, higher levels of Pb (25.43 ± 2.68 mg/kg) and Cd (1.67 ± 0.06 mg/kg) contents were reported in the LHDW, elevated concentrations of Cr (83.11 ± 5.80 mg/kg) and Ni (45.91 ± 3.02 mg/kg) were analysed in the YRDW, and a higher value of Zn (120.86 ± 7.41 mg/kg) was measured in the QLHW (Figure 2, Table 2).

Additionally, the Cd contents in all wetlands were higher than the corresponding background values of Cd in sediments around the Bohai Sea (Table 2) (Xu et al. 2017). By comparison, the Pb (25.43 ± 2.68 mg/kg), Ni (28.08 ± 4.31 mg/kg), Zn (80.45 ± 9.60 mg/kg), and Cu (26.72 ± 3.31 mg/kg) contents in the LHDW were higher than the background values (Pb, 21.4 mg/kg; Ni, 25.6 mg/kg; Zn, 63.5 mg/kg; and Cu, 19.8 mg/kg) in Liaoning Province, while the Cr (83.11 ± 5.80 mg/kg), Ni (45.91 ± 3.02 mg/kg), and Zn (74.86 ± 8.74 mg/kg) in the YRDW were higher than the background values (Cr, 66 mg/kg; Ni, 25.8 mg/kg; and Zn, 63.5 mg/kg) in Shandong Province. Moreover, the Zn content in the BHBW, such as the BDGW (81.94 ± 1.42 mg/kg) and the QLHW (120.86 ± 7.41 mg/kg), were higher than the background values (77.5 mg/kg) of the sediment. As a result, the heavy metal content varied significantly among these wetlands, and relatively higher

Table 1. Physical and chemical properties of reed wetland around Bohai Sea

Location	Wetland	Water content (%)	pH	Water-soluble salt content (g/kg)	TOC	Clay	Silt	Sand
					(%)			
YRDW	YRW1	29.96 ± 0.19	7.93 ± 0.12	2.67 ± 0.09	0.66 ± 2.34	7.79 ± 0.84	28.67 ± 4.28	63.54 ± 4.99
	YRW2	22.47 ± 0.23	7.66 ± 0.22	1.93 ± 0.33	0.34 ± 1.46	4.64 ± 0.52	22.96 ± 2.22	72.4 ± 6.87
	YRW3	23.94 ± 0.17	8.02 ± 0.21	4.56 ± 0.04	1.24 ± 1.47	8.36 ± 0.74	24.9 ± 4.76	66.74 ± 5.44
BHBW	HXW	28.3 ± 0.35	8.54 ± 0.23	4.7 ± 0.18	0.79 ± 0.38	9.84 ± 6.23	22.15 ± 9.82	68.01 ± 4.59
	NDGW	28.6 ± 2.2	8.56 ± 0.04	4.09 ± 0.26	1.14 ± 0.16	5.38 ± 0.14	27.82 ± 0.19	66.8 ± 0.33
	BDGW	28.6 ± 2.47	8.21 ± 0.1	1.52 ± 0.04^{d}	2.84 ± 0.59	2.79 ± 0.88	15.84 ± 3.96	81.37 ± 4.83
	QLHW	37.3 ± 2.15	8.6 ± 0.17	1.66 ± 0.18	5.7 ± 0.17	2.3 ± 0.16	16.47 ± 2.38	81.23 ± 2.53
LHDW	LHW1	34 ± 3.15	7.87 ± 0.01	8.9 ± 1.61	1.61 ± 0.34	7.26 ± 0.15	39.73 ± 0.35	53.02 ± 0.2
	LHW2	25.1 ± 3.33	7.85 ± 0.1	7.4 ± 0.14	0.73 ± 0.11	3.56 ± 0.33	20.77 ± 2.09	75.67 ± 2.41
	LHW3	39.9 ± 2.15	7.91 ± 0.1	13.44 ± 0.14	0.21 ± 0.13	3.41 ± 0.63	18.17 ± 4.96	78.42 ± 5.55

TOC – total organic carbon; Yellow River Delta wetlands (YRDW), including Experimental Zone wetland (YRW1), Buffer Zone wetland (YRW2) and Key Zone wetland (YRW3); Bohai Bay coastal wetlands (BHBW), including Haixing Wetland (HXW), Nandagang Wetland (NDGW), Beidagang Wetland (BDGW) and Qilihai Wetland (QLHW); Liaohe Delta wetlands (LHDW), including Experimental Zone wetland (LHW1), Buffer Zone wetland (LHW2) and Key Zone wetland (LHW3)

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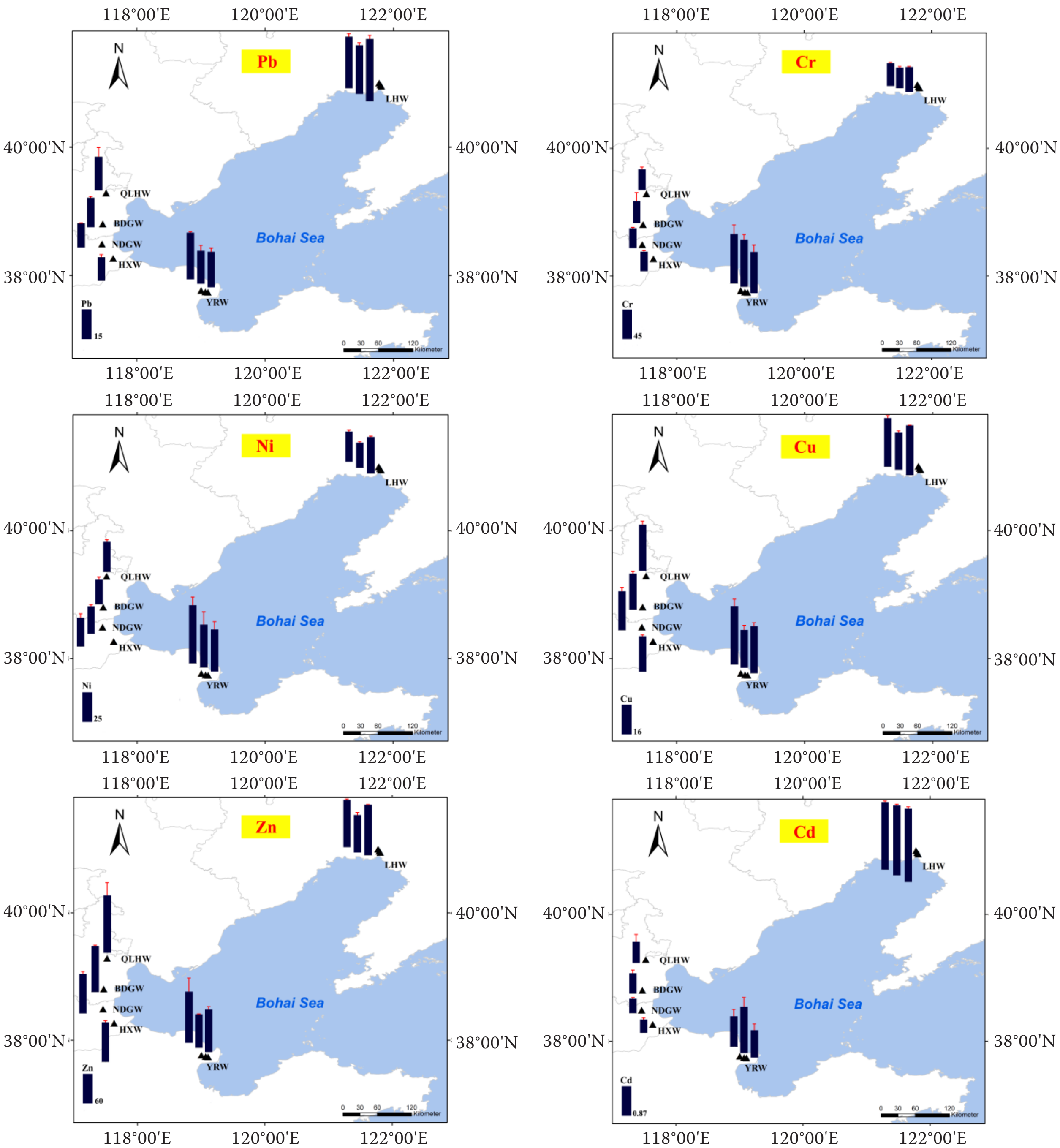

Figure 2. Heavy metal content in reed wetlands around the Bohai Sea. QLHW – Qilihai Wetland; BDGW – Beidagang Wetland; NDGW – Nandagang Wetland; HXW – Haixing Wetland; YRDW – Yellow River Delta wetlands

values were found in the LHDW and YRDW than in the BHBW. In particular, Cd was a prevalent pollutant in the reed wetlands surrounding the Bohai Sea.

Factors influencing heavy metal contents

The correlation analysis between physiochemical properties and heavy metal contents in reed wetlands around the Bohai Sea is shown in Figure 3. There are significant positive correlations between water content (WC) and Zn ($P < 0.01$), TOC and Zn ($P < 0.01$), pH and Cd ($P < 0.05$), and WSSC and Cd ($P < 0.05$). Clay and silt contents were positively correlated with Ni, Cr, and Cu concentrations ($P < 0.05$). Some heavy metals, such as Pb, Cu, Ni, and Cd, were correlated, suggesting that these heavy metals may have origi-

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Table 2. Description of heavy metal content (mg/kg) in reed wetland around Bohai Sea

Characteristic parameter	Pb	Cr	Ni	Cu	Zn	Cd
Maximum	29.18	89.30	50.18	32.13	120.86	1.74
Minimum	9.87	34.96	18.15	19.03	62.74	0.32
Average value	17.92	50.29	31.53	25.37	80.13	0.92
Standard deviation	5.81	20.50	9.71	4.29	15.11	0.54

nated from similar sources or may be controlled by the same processes.

Risk assessment of heavy metals

Geo-accumulation index. The I_{geo} of Cd ranged from 1.23 to 3.55, which indicates a high level of Cd pollution in reed wetlands around the Bohai Sea (Figure 4). The levels of Cd pollution in each wetland follow the order of LHDW > YRDW > BHBW (Figure 5). In addition, the I_{geo} of the other five heavy metals was < 0, which indicates no pollution from these metals.

Potential ecological risk index. As shown in Figures 6 and 7, the extent of heavy metal pollution ranked by element is Cd > Ni > Cu > Pb > Cr > Zn. The relatively high level of Cd showed the heaviest pollution value of $E_r^i > 40$ among the six elements analysed. In contrast, the pollution levels of the other five heavy metals were in the low ecological risk level for all wetlands ($E_r^i < 40$). Cd was ranked at the very high ecological risk level in the LHDW and the YRDW ($E_r^i > 320$), and in the high ecological risk level in the BDGW and the QLHW ($160 < E_r^i < 320$). Finally, Cd was ranked in the moderate ecological risk level in the HXW and the NDGW ($80 < E_r^i < 160$).

The R_i in the YRDW and the LHDW (range: 300–600) indicates a very high ecological risk while the R_i of the BDGW and the QLHW (range: 150–300) suggests a moderate ecological risk. Low ecological risk ($R_i < 150$) was observed in the HXW and the NDGW.

Nemerow pollution index assessment. The Nemerow pollution index of the heavy metals for the wetlands is shown in Table 3. The pollution levels of Pb, Cr, Ni, Cu, and Zn do not indicate pollution, while the pollution level of Cd indicates severe pollution. These data are consistent with the heavy metal pollution assessment for the wetlands based on the I_{geo} and the potential ecological risk index.

All three pollution indices showed severe Cd pollution in these wetlands, with Cd contamination in the LHDW and YRDW higher than in the BHBW.

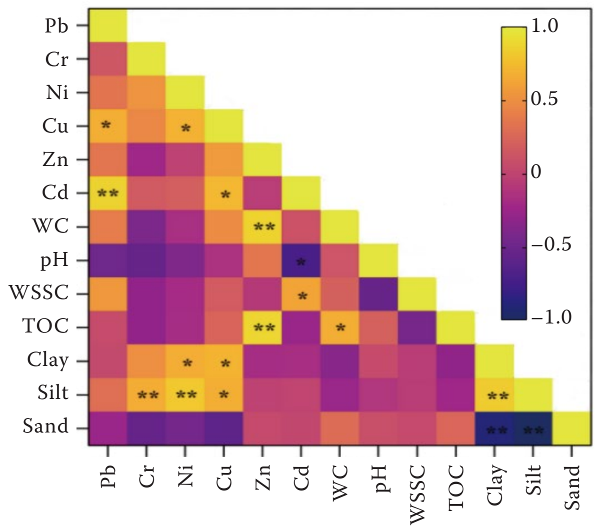

Figure 3. Correlation analysis between sediment physiochemical properties and heavy metals in reed wetlands around the Bohai Sea. **$P < 0.01$; *$P < 0.05$; WC – water content; WSSC – water-soluble salt content; TOC – total organic carbon

DISCUSSION

Influence of sediment characteristics on heavy metals content

The distribution, mobility, and bioavailability of heavy metals in wetlands can be affected by sediment physiochemical properties (Bai et al. 2011, Zhang et

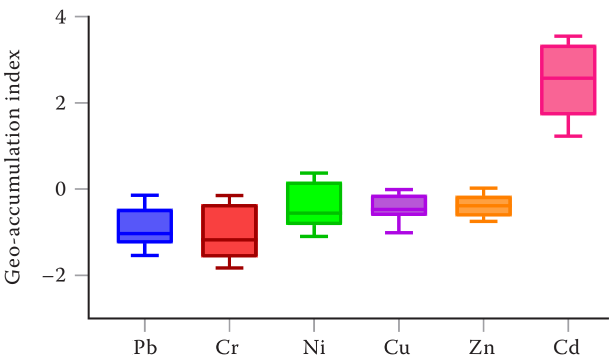

Figure 4. Geo-accumulation index of six heavy metals in reed wetlands around the Bohai Sea

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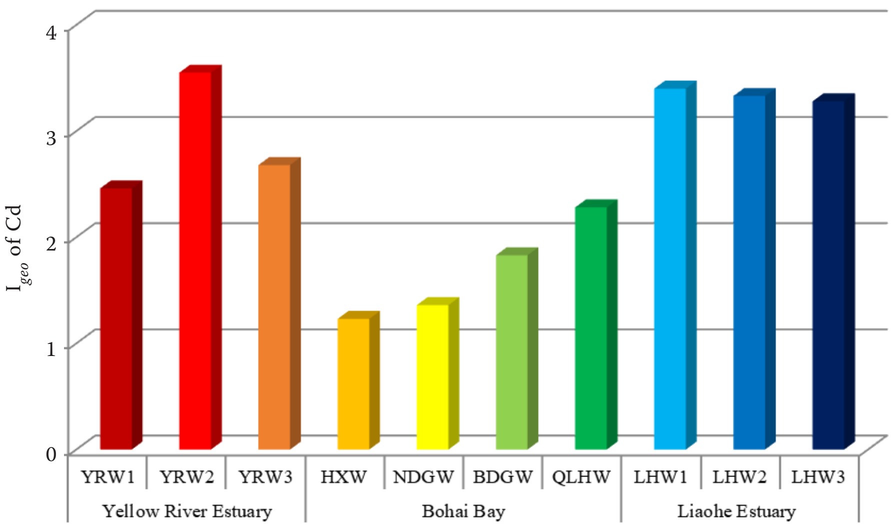

Figure 5. Geo-accumulation index (I_{geo}) of cadmium (Cd) in wetlands around Bohai Bay. YRW1 – experimental zone wetland; YRW2 – buffer zone wetland; YRW3 – key zone wetland; HXW – including Haixing Wetland; NDGW – Nandagang Wetland; BDGW – Beidagang Wetland; QLHW – Qilihai Wetland; LHW1 – Experimental Zone wetland; LHW2 – Buffer Zone wetland; LHW3 – Key Zone wetland

al. 2021). There is a significant positive relationship between clay/slit content and Cu, Cr, and Ni content in wetlands. These data suggest heavy metals mainly bind with fine particles in the sediments. The fine-grained sediments tend to contain higher sorption sites for heavy metal immobilisation (Zhang et al. 2021). Sun et al. (2018) suggested that heavy metal distribution could be primarily related to the fine sediment texture in the Yangtze River Estuary. Heavy metal concentrations in coastal wetland sediments were positively correlated with organic matter content. The large sorption capacities of TOC leads to the immobilisation of heavy metals from the overlying water and the deposition of heavy metals in sediments (Zhang et al. 2021). The organic matter also immobilises heavy metals in polluted samples (Zhao et al. 2021). Therefore, SOC can be a significant heavy metal sink in wetlands. These findings are supported by the fact that the heavy metal content was higher in restored wetlands compared to degraded wetlands (Table 2). The restoration measure has effectively increased the plant biomass and sediment organic matter content in these degraded coastal wetlands (Bai et al. 2011). Consequently, the wetland restoration project increased the concentration of heavy metals in sediment, thereby reducing the release of heavy metals.

Additionally, heavy metal content is inversely correlated with sediment pH. Decreased heavy metal pollution by enhancing the sediment pH is generally observed in acid sediments (Liu et al. 2016). As sediment pH changes, the CEC of the sediment changes and affects the mobility and distribution of heavy metals (Zhang et al. 2021). The higher water content tends to increase the concentration of heavy metals in the wetlands because the potential

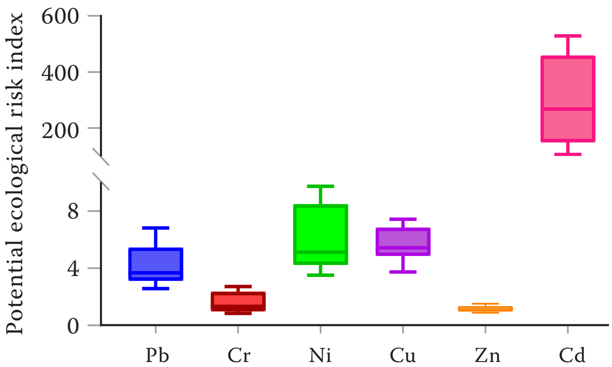

Figure 6. Heavy metals in sediment of reed wetlands around the Bohai Sea

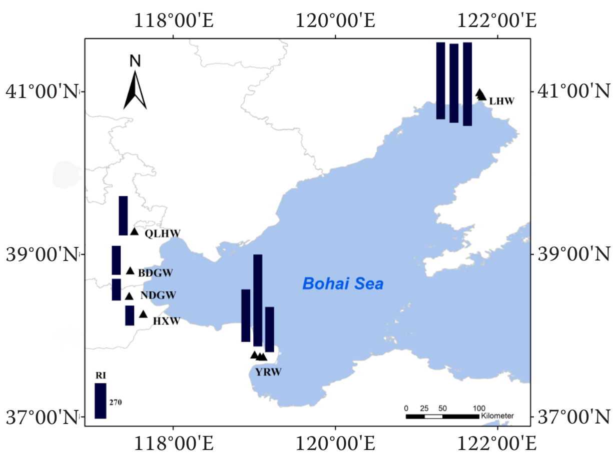

Figure 7. Potential ecological index of heavy metals in reed wetlands around the Bohai Sea. QLHW – Qilihai Wetland; BDGW – Beidagang Wetland; NDGW – Nandagang Wetland; HXW – Haixing Wetland; YRDW – Yellow River Delta wetlands

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Table 3. Nemerow comprehensive pollution index (P_N) of heavy metal in reed wetland around Bohai Sea

	Pb	Cr	Ni	Cu	Zn	Cd
P_N	0.37	0.37	0.51	0.43	0.47	4.92
Pollution level	unpolluted	unpolluted	unpolluted	unpolluted	unpolluted	severely polluted

mobility of heavy metals generally increases with the increasing sediment water content (Zhao et al. 2021). The heavy metal content has little relationship with sediment salinity, consistent with previous research (Bai et al. 2011).

Different sources of heavy metals in reed wetlands surrounding the Bohai Sea

This study shows that Cd contamination has polluted the sediments in reed wetlands surrounding the Bohai Sea. At the same time, Pb, Cr, Ni, Cu, and Zn have caused relatively lower contamination levels. The Cd pollution in soils, rivers, and sediments primarily originated from pesticides or fertiliser application, mining activities, industrial and agricultural wastewater irrigation, and automobile emissions (Bai et al. 2011, Wang et al. 2011, Zhang et al. 2020, 2021). Moreover, Cd has a higher bio-toxicity and is more easily enriched by wetland organisms, leading to higher sediment accumulation (Dai et al. 2013). Consequently, greater attention should be paid to Cd pollution in coastal wetland sediments in China.

The measured heavy metals content generally followed the spatial distribution of LHDW > YRDW > BHBW. Previous studies have reported similar spatial characteristics of heavy metal content in coastal sea sediments. For example, Cd contamination was higher in the sediments of Laizhou Bay (Liu et al. 2012, Zhao et al. 2021) and Liaodong Bay (Lan et al. 2018, Yan et al. 2020), but Cd pollution was lower in the sediments of Bohai Bay (Chen et al. 2017, Wang et al. 2017). Three explanations may account for the spatial variation of heavy metals in these wetlands. First, oil was produced in the LHDW and the YRDW, and it was reported that crude oil contained 12 types of metallic elements (Li et al. 2019, Miao et al. 2019). Therefore, heavy metal pollution in oil production areas may originate from crude oil leakage or transportation (Zhang 2006) or the chemical additives in crude oil production that contain heavy metals (Zou et al. 2019). Second, aquaculture fisheries are found within the LHDW and YRDW. The fisheries' bait, drugs, and disinfectants can lead to excessive heavy metal pollution in water bodies and sediments (Zhang 2006, Mokhtar et al. 2009, Farmaki et al. 2014). Finally, the relatively higher pH of sediments in the BHBW (Table 1) contributed to the lower heavy metal content because a decreasing trend of heavy metal content is observed when sediment pH increases (Dai et al. 2013).

In general, more focus on Cd pollution is needed, especially in the food chain, to reduce potential ecological risks in the coastal wetlands surrounding

Table 4. Comparisons of the heavy metals contents (mg/kg) in Chinese coastal reed wetlands

Studied region	Pb	Cr	Ni	Cu	Zn	Cd	Reference
Bohai Rim Coastal Wetland	17.92 ± 5.81	50.29 ± 20.50	31.53 ± 9.71	25.37 ± 4.29	80.13 ± 15.11	0.92 ± 0.54	The present study
Pearl River Estuary Wetland	40.9 ± 15.7	82.3 ± 21.3	39.1 ± 17.4	47.6 ± 20.2	134.7 ± 36.2	0.37 ± 0.41	Gan et al. (2010)
Yangtze River Estuary Wetland	77.43 ± 3.02	100.88 ± 3.40	–	14.84 ± 1.24	92.06 ± 3.22	1.11 ± 0.04	Zhang et al. (2021)
Minjiang Estuary Wetland	99.12 ± 18.39	58.04 ± 20.72	49.8 ± 31.37	45.22 ± 9.70	123.67 ± 22.68	0.24 ± 0.23	Hou et al. (2009)
Guangxi Coastal Wetland	46.99 ± 20.14	110.71 ± 30.84	39.68 ± 13.93	38.76 ± 27.51	141.25 ± 126.62	0.67 ± 0.39	Xu et al. (2016)
Jiangsu Coastal Wetland	26.28 ± 4.01	57.71 ± 15.68	–	27.55 ± 12.03	70.05 ± 14.87	1.04 ± 0.35	Luo et al. (2018)

– not determined

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the Bohai Sea. In particular, ecological restoration of the LHDW and YRDW are needed to minimise the environmental impacts caused by excessive Cd pollution.

Comparison of heavy metal pollution with other coastal wetlands in China

The heavy metals content in Chinese coastal wetlands is presented in Table 4. The heavy metal pollution of the Yangtze River and the Pearl River estuary wetlands is higher than that of the Bohai Sea wetlands. The concentrations of heavy metals (except for Cd) were higher in the Minjiang estuary wetlands compared to the Bohai Sea wetlands. There was no significant difference in heavy metal content between the Subei coastal wetlands and the Bohai sea wetlands.

Two factors may be responsible for the distribution of heavy metals in these wetlands. First, large quantities of heavy metals have been discharged from industry, agriculture, and sewage in the Yangtze River Basin and the Pearl River Basin, China's most economically developed regions (Pan and Wang 2012). Second, coastal wetlands in southern China (such as the Yangtze River Estuary, Pearl River Estuary, and Minjiang River Estuary) show relatively lower sediment pH than the wetlands around the Bohai Sea. Some studies have indicated that this heavy metal content significantly increased with rising sediment pH (Liu et al. 2021), and soil acidification may have enhanced the solubility of heavy metals in soil minerals as well (Dai et al. 2013). As a result, the relatively lower sediment pH may be responsible for the higher heavy metal content in the southern Chinese coastal wetlands.

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